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Mathematics Education in Africa

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Chapter 6
Transforming the Zimbabwean Secondary School Mathematics Curriculum to Align It with the Demands of the Fourth Industrial Revolution

Gladys Sunzuma, Brantina Chirinda, and Conilius Chagwiza

Introduction

Globally, various sectors, including the education sector, have embraced the Fourth Industrial Revolution (4IR) to address the challenges faced by African citizens. These challenges include climate change, drought, poverty, inequalities and the need to equip learners with twenty-first-century skills required in an ever-changing society. Zimbabwe is undergoing a socio-economic transformation where mathematics is key to development. Learners must acquire the necessary mathematical knowledge and skills and develop a positive attitude towards the learning area. To equip the learners with skills needed for the future industry and be ready for the 4IR, they need access to the mathematics curriculum that promotes technology-driven pedagogies. Technology-driven pedagogies are essential in fostering learners' problem-solving skills, critical thinking, collaboration and effective communication. The chapter focuses on how the Zimbabwean secondary school mathematics curriculum can be transformed to align it with the 4IR requirements. We formulated the following research question: How should the Zimbabwean mathematics curriculum be transformed to align it to the requirements of the fourth industrial revolution?

The chapter is organised in seven major sections: introduction, the 4IR; 4IR and mathematics education; focus and purpose of the chapter; methodology; findings and discussion; transforming the Zimbabwean secondary school mathematics curriculum to align with the 4IR requirements; and conclusion.

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The Fourth Industrial Revolution

People's lives and work have changed due to the 4IR (Schwab, 2016). The industrial revolution has undergone several stages, from the first to the fourth industrial revolution. Figure 6.1 shows the four industrial revolution stages.

The first industrial revolution (1IR), which stretched from 1760 to 1830, was characterised by the cotton gin, continent-wide railroad, electricity, and steam engines (Moloi & Mhlanga, 2021; Fomunyam, 2020). The systems mechanisation that characterised the 1IR led to the development of educational technologies, such as the graphite pencil, mechanical printing, typewriter, ballpoint pen, and paper-making machine. The teaching and learning of mathematics and other subjects were rooted in behaviourism and essentialism philosophies (Miranda et al., 2021). Teachers were at the centre of education, while learners were passive recipients.

The second industrial revolution (2IR), also recognised as the technological revolution, occurred between 1870 and 1914. The 2IR was characterised by technological innovations which focused on the expansion of electricity, and the production of steel and petroleum, which resulted in the manufacturing of aeroplanes and automobiles (Fomunyam, 2020). Some of the fundamental developments of the 2IR were the telephone, internal combustion engine, and light bulb (Schulze, 2019). The open-source resources from the libraries were the primary information sources. The technological developments during the 2IR resulted in educational electronic devices such as computers, calculators and printers. The 2IR was based on educational philosophies such as constructivism and andragogy. The role of the teacher changed from sagacious to being the source of information to help develop the materials for professional application. The role of the learner remained that of a

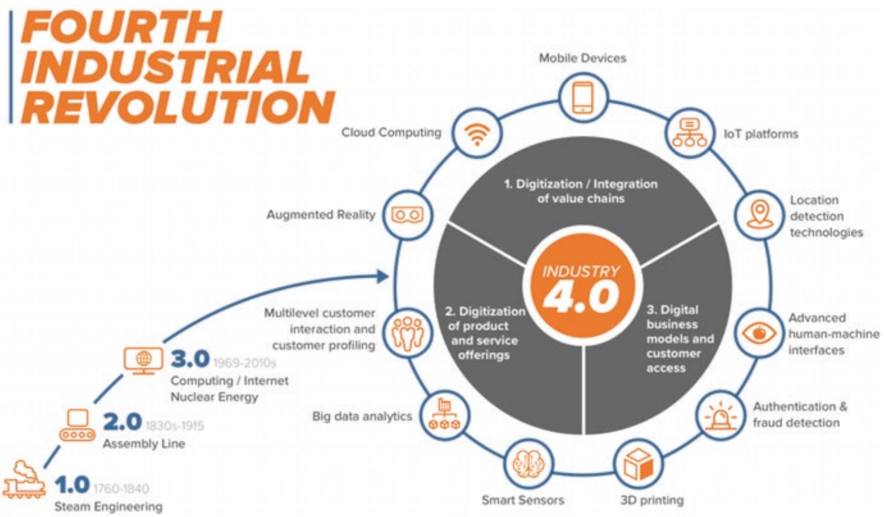

Fig. 6.1 The Dawn of 4IR (Schwab, 2016)

passive recipient. Learning was teacher-centred with encouragement on peer assessment and practices, for instance, broadcast education and correspondence education.

The third industrial revolution (3IR) began in the 1950s and is well-known as the digital revolution. The significant features of 3IR were personal computing, mainframe computing, semiconductors, and the internet used for phones, tablets and laptops (Marwala, 2020). Modern 3D printing, known as additive manufacturing, was another component of the 3IR. The 3IR marked the transition in which the teachers and the learners did not have to be involved sorely in synchronous teaching and learning sessions. Various resources reinforced new teaching and learning procedures, e.g., virtual laboratories, online tools and multimedia. The teaching and learning methodologies were more connectivist and heutagogical (Miranda et al., 2021). The teacher was regarded as a curator, collaborator and orchestrator, and the learner was empowered to construct knowledge.

Developing specific technologies that change society is a common feature of industrial revolutions (Moloi & Marwala, 2021). According to Schwab (2016), the 4IR is principally different from the preceding revolutions. The new revolution amalgamates the technologies and their interaction across the biological, digital and physical domains to nurture an all-encompassing, human-centred future. It focuses on innovative approaches to attaining the utmost good for the majority of the people, societies and organisations; it concentrates on how to improve life for the world's populace (Finley-Moise, 2019). The 4IR is a distinctive stage characterised by extraordinary scope, velocity and system impacts of technological innovations (Schwab, 2016).

Features of the Fourth Industrial Revolution

To understand the significance of 4IR in expediting teaching and learning practices, it is vital to have adequate knowledge of the various components of 4IR. The 4IR has led to disruptive technologies and trends, for example, Artificial Intelligence (AI), 3D printing, Virtual Reality (VR), Computational Thinking (CT), Augmented Reality (AR), robotics, and the Internet of Things (IoT) (Schwab, 2016). Embracing the components of 4IR implies that teaching mathematics is not limited to using a computer, particularly in the education sector, where opportunities such as developing an ecosystem might help share learning materials and data analytics to meet the learners' needs. In addition, biotechnology, nanotechnology, quantum computing and renewables are aspects of the 4IR (Schwab, 2016), which go beyond using computers and smart technology when teaching mathematics.

Artificial Intelligence (AI)

Artificial intelligence is the technology development that reproduces and develops human intelligence (Kambria, 2019). Technological advancements have resulted in an increased role AI plays in teaching mathematics. Gadanidis (2017) argues that AI affords numerous opportunities to design intelligent artefacts for mathematics teaching and learning. These interactive platforms explain mathematical ideas and theories, help solve problems and let students respond to each other.

Robotics

According to Perez et al. (2018), robotics resulted from improvements in computing, electrical engineering, and mechatronics. Robots are automated motorised teaching and learning materials that allow learners to comprehend logical and engineering concepts in action and enact mathematics concepts (Leoste & Heidmets, 2019). Educational robotics, which have become prevalent, comprises various modular educational robotics kits for developing programmable robots with intertwining plastic parts, such as Robotics Dream, VEX robots, LEGO MINDSTORMS and LEGO WeDo (Sisman et al., 2021). Educational robotics involves learners in interactive and hands-on activities and enables them to work together to understand the association between science, technology, engineering and mathematics (STEM) focused activities (Sisman et al., 2021).

Three-Dimensional (3D) Printing

Designing solid 3D objects from a digital file is known as 3D printing or additive manufacturing (Chow-Miller, 2018). It is cheaper and faster to design objects using 3D printing. In mathematics education, learners make 3D objects from geometrical designs instead of being provided with physically-build 3D objects. This allows them to be knowledge producers and not consumers of knowledge (Ng & Ferrara, 2020). The making of 3D objects requires incorporating skills and knowledge from diverse areas such as mathematics, computer science, and the science of materials and design (Budinski et al., 2019). 3D printing enhances learners' visualisation skills by designing and observing the finished objects. In addition, 3D printing enables the teachers to integrate project-based learning in mathematics teaching, whilst the learners experience the amalgamation of STEM subjects (Ng, 2017).

Computational Thinking (CT)

Computational thinking (CT) skills comprise the breakdown of complex problems into sub-problems using a set of rules that provide a sequence of stages in solving problems, investigating how a solution may be applied to similar problems through abstraction, and finding out whether computers can assist in solving such problems more efficiently through the use of automation (Yadav et al., 2016). An essential benefit of CT is automation, which involves programming environments, software modelling, and spreadsheet apps that help computers execute repetitive tasks (Hsu et al., 2018). CT involves data analysis, system thinking, programming, models, simulations and algorithmic thinking. It may be integrated into the mathematics curriculum through problem-solving.

Augmented Reality (AR) and Virtual Reality (VR)

Augmented reality (AR) is a technology used in overlaying reality using virtual objects in real-time and with the probability of interaction (Schutera et al., 2021). The way of comprehending is changed by integrating visual and sensory information using AR. AR uses 3D visualisations in real space, directly connecting them to the learning content in mathematics, such as geometry, which requires spatial imagination (Schutera et al., 2021). Virtual Reality (VR) is a simulated exercise where the learner can explore a collaborative computer-generated environment (İbili et al., 2020). VR and AR require a visualisation component that might be a traditional screen, such as computer monitors, mobile devices, and a head-mounted display (HMD). VR and AR are used in mathematics to explore spaces inaccessible because of physical restrictions, carry out experiments that would be intolerable due to risks or costs, and develop visualisation skills and spatial abstraction (İbili et al., 2020).

The Internet of Things (IoT)

Technological advancement has resulted in new notions of IoT. The IoT has made it possible for various electronic devices such as mobile devices, television sets and computers to connect to one another as well as the internet. The connection through the internet allows the sending and receiving of information from different devices. IoT is the network of physical objects or systems such as cloud technologies, wireless connections, embedded sensors, and actuators that communicate, sense, or interact with their interior environments or the exterior setting (Aheleroff et al., 2020). According to Karabegovi and Husak (2018), the digital interaction among and within devices and systems is central to the 4IR. Using actuators and sensors through IoT, collecting chemical, physical and biological data by learners from their environment allows the amalgamation of STEM disciplines. This leads to learners' awareness of the association between sciences and mathematics. One of the benefits of the IoT is immersing learners in mathematically-meaningful settings that enable them to value mathematics learning. IoT encourages inquiry-based learning that involves learners integrating mathematics with everyday situations (Kusmin, 2019).

The Fourth Industrial Revolution and Mathematics Education

Education in the 4IR incorporates new Infrastructure and evolving technologies. It goes beyond pedagogy and andragogy – towards an approach that merges *cybergogy*, *peeragogy and heutagogy* (Miranda et al., 2021). Cybergogy, which has resulted from technological advancements and the evolutions of the internet, is defined as learning approaches supported by ICTs that provide learning experiences that outdo space and time restrictions. Peeragogy talks about collaborative learning and encourages teaching methods that support learning amongst peers. Heutagogy encourages self-learning grounded in constructivist and humanist ideologies. It is centred on the learner whose understanding of the learning process is encouraged. Education during the 4IR promotes a transition from teacher-centred to learner-centred approaches and from passive to active learning.

Miranda et al. (2021) propose four principal components of education during the 4IR era, which are: (a) Competencies (training and development of desirable critical competencies in today's learners), (b) Learning Methods (incorporation of new learning methods), (c) Information and Communication Technologies (ICTs) (implementation of current and emerging ICTs), and (d) Infrastructure (use of innovative facilities, services, and systems to improve learning processes). Table 6.1 shows the four major components of 4IR education used to analyse the data in this study.

The above 4IR features allure to experiential learning, making mathematics concepts more accessible to learners. The amalgamation of knowledge from diverse subjects or topics allows mathematics applicability to be visible, including the opportunities for creativeness, invention, and problem-solving skills in realistic situations – the 4IR advocates for a project-based component and realistic learning experiences in the mathematics curriculum. The 4IR is a medium for altering mathematics teaching and learning from the accrual of principles, conventions and facts, which is usually the case in schools to mathematical applications and innovative activities. For the learners to be prepared to meet the ever-changing societal demands and problems, they should be educated differently from the past.

The 4IR has brought various changes in all sectors, fields and spheres of life, including education and industry. Technological changes such as AI and the IoT in the 4IR have varied implications for education and skills development. For example, the revamp of the education systems and tactical methods to increase creativeness and innovation. Zimbabwean education needs to be responsive to the 4IR so that learners are adequately prepared and armed to succeed in their future workplace. Responsiveness means that the curriculum can produce tech-savvy learners that can manage the workplace's digitisation in the 4IR era.

According to Schwab (2016), it has been established that societies and people who benefit more from the 4IR are those that can meet the expense of buying data and have access to the digital world. In Zimbabwe, digital resources are limited in most schools, yet the curriculum recommends using digital tools. The Zimbabwean curriculum has been described as too academic and insufficient to develop the needed human capital for the present 4IR (Moyo, 2022). The Zimbabwean curriculum does not specify how the technologies should be included in the teaching and learning of mathematics. For the 4IR to be extended to schools, the technology must be embedded into the education system to scale up the effectiveness of technology use in the education system in Zimbabwe. In terms of how the content is supposed to be delivered, the curriculum does not equip learners with the essential skills that

Table 6.1 Four components of Education 4.0

Categories		
Competencies	Transversal competencies	(a) Critical thinking, (b) cooperation, (c) collaboration, (d) communication, (e) creativity
	Disciplinary competencies.	(a) Training and developing functional, technical, and technological knowledge and successful workplace performance skills. (b) The capacity to research, design, create and implement new technologies. (c) The use of emerging technologies and best practices to propose technology-based solutions.
Learning methods	Learning delivery modalities.	(a) Face-to-face. (b) Learning is based mainly on active learning. (c) Online distance learning. (d) Hybrid learning.
	Learning strategies	Pedagogical approaches such as challenge-based learning, problem-based learning, learning-by-doing, and gamification-based learning.
Information and communication technologies (ICT) categories	Technology-based	Artificial intelligence and machine learning, high-data-processing applying data science, data analytics and cloud computing, and virtual image, processing for virtual and experiential environments.
	Tools and platforms	Synchronous online sessions to support student learning through web conference technologies (e.g., ZOOM, Meets, Webex, M-teams) and asynchronous learning platforms (Learning Management Systems, (LMS)).
Infrastructure levels	Classroom level	Innovative furniture; connected tools; classrooms, rooms, and libraries adapted with specific architecture, colours, illumination, sounds, and temperature to improve learning; virtual and augmented reality; and hologram systems.
	Institutional level	Includes recreation, comfort, sustainability, and accessibility; services such as online libraries, instant messaging systems, remote laboratories enabled and widely used; access to internet services.

Source: Miranda et al. (2021)

integrate mathematics with other subjects required for the 4IR. Teachers and learners are required to adapt to the era of digital technologies in 4IR that requires expertise and qualitative skills (Moyo, 2022), and yet Zimbabwe has been undergoing several economic challenges that have major negative effects on the education sector.

Methodology

The chapter focuses on how the Zimbabwean secondary school mathematics curriculum can be transformed to align it with the requirements of the 4IR. We used a curriculum analysis matrix to examine the four Zimbabwean secondary school mathematics curriculum documents to achieve this goal. The analysis was done in line with the four major components of 4IR presented in Table 6.1. The Zimbabwean competence-based curriculum has four different secondary school mathematics syllabi: the mathematics syllabus for Forms 1 up to 4 and the pure mathematics syllabus, statistics syllabus, and additional mathematics syllabus meant for Forms 3 and 4.

Findings and Discussion

We analysed the four Zimbabwean secondary school mathematics curricula to identify their relevance to the 4IR. The findings from the analysis are presented in Table 6.2 using the following categories: Content, Competencies, Teaching-learning methods, Technologies and Infrastructure.

Content

The content of the mathematics syllabus at the secondary school level has not changed since Zimbabwe gained its independence in 1980. It focuses on Numbers, Algebra, Geometry, Measurement, Vectors, Matrices, Probability and Statistics. Nonetheless, significant changes are noticeable in the teaching and learning resources; for example, there is a shift from using logarithm tables to calculators. The content in the four syllabuses is taught separately; however, teachers are encouraged to integrate mathematics into other learning areas and real-life situations. The 4IR advocates integrating STEM subjects, implying the four Zimbabwean mathematics syllabuses should not be taught separately. The topics such as vectors, matrices and sets are important in aspects of the 4IR such as artificial intelligence (AI). However, the syllabuses do not guide what is to be taught, when it will be taught, and the level to integrate it.

Competences

For learners to compete in the 4IR era, they need good communication skills, self-confidence, critical thinking skills, the ability to work together, and innovative and creative abilities (Sumar et al., 2019). Problem-solving and critical thinking are critical to the 4IR and are recommended in all four syllabuses. However, the challenge is how Zimbabwean learners can attain these skills in the classroom. The statistics syllabus is the only one that recommends that learners should have gained technology and innovation skills after completing Ordinary Level studies. Although creativity and innovativeness are indicated in the additional mathematics syllabus

Table 6.2 An analysis of the four Zimbabwean competence-based mathematics curricula in line with the components of 4IR education

Syllabus	**Mathematics syllabus (Forms 1–4)**
Content	(1) Real numbers (2) Sets (3) Financial Mathematics (4) Measures and mensuration (5) Graphs (6) Variation (7) Algebra (8) Geometry (9) Statistics (10) Trigonometry (11) Vectors (12) Matrices (13) Transformation (14) Probability
Competencies	It desires to produce learners with the ability to communicate effectively…p. 5. This will enable learners to be creative thinkers and problem-solvers ……p. 5.
Teaching-learning methods	The teaching and learning of mathematics must be learner-centred. The following are some of the suggested methods of the teaching and learning of mathematics guided discovery, discussion, interactive e-learning, exposition, demonstration and illustration, problem-solving, individualisation, simulation, visual-tactile, educational tours and expert guest presentation. p. 6 Six periods of 40 min each per week ….p. 6.
Technologies	Use ICT tools in problem-solving. p. 6 Use ICT tools to solve mathematical problems. p. 6
Infrastructure	None was specified.
Syllabus	**Pure mathematics syllabus (forms 3–4)**
Content	(1) Indices and irrational numbers (2) Polynomials (3) Identities, equations and inequalities (4) Graphs and coordinate geometry (5) Vectors (6) Functions (7) Sequences (8) Binomial expansions (9) Trigonometry (10) The logarithmic and exponential function (11) Differentiation (12) Integration (13) Numerical methods
Competencies	The syllabus intends to produce a citizen who is a critical thinker and problem solver. p. 5. Communicate mathematical ideas successfully. p. 6
Teaching-learning methods	The teaching and learning of pure Mathematics must be learner-centred and ICT driven. The following are suggested methods for teaching and learning pure Mathematics guided discovery, group work, interactive e-learning, games and puzzles, quiz, problem-solving, simulation and modelling and experimentation. p. 6 Six periods of 40 min each per week were allocated.
Technologies	Use ICT tools for learning and solving mathematical problems. p. 5 Use ICT tools for learning through problem solving. p. 6.
Infrastructure	None was specified.
Syllabus	**Additional mathematics syllabus (forms 3–4)**
Content	*Pure mathematics* (1) Indices and irrational numbers (2) Polynomials (3) Algebraic identities, equations and inequalities (4) Sequences and series (5) Coordinate geometry in two dimensions (6) Functions (7) Quadratic functions (8) Logarithmic and exponential functions (9) Trigonometrical functions (10) Differentiation (11) Integration *Probability and statistics* (1) Probability (2) Data collection and presentation (3) Measures of central tendency and dispersion (4) Discrete and continuous probability distributions (5) Normal distribution (6) Sampling methods (7) Estimation *Mechanics* (1) Kinematics of motion in a straight line (2) Forces and equilibrium (3) Newton's Laws of motion (4) Energy, work and power

(continued)

Table 6.2 (continued)

Competencies	Enhance confidence, critical thinking, innovativeness, creativity and problem-solving skills for sustainable development. p. 5–6.
Teaching-learning methods	The teaching and learning of mathematics must be learner-centred and practically oriented. The following are suggested methods guided discovery, collaborative learning, project-based learning, group work, interactive e-learning, problem-solving, simulation, visual-tactile, and educational tours. p. 6.
Technologies	Use ICT tools effectively to solve mathematical problems. p. 5. Use ICT tools responsibly in problem solving. p. 6.
Infrastructure	None was specified.
Syllabus	**Statistics syllabus (forms 3–4)**
Content	(1) Introduction to statistics (2) Data collection and presentation (3) Measures of central tendency (4) Measures of dispersion (5) Sampling (6) Probability (7) Random variables (8) Errors (9) Index numbers (10) Time series (11) Linear regression
Competencies	The statistics syllabus enables learners to develop skills in problem solving, critical thinking, decision making, leadership, self-management, communication, technology and innovation, and enterprise. p. 5
Teaching-learning methods	The following learner-centred and participatory methods are recommended in teaching statistics: Demonstrations, discovery, experimentation, group work, question and answer, problem solving, discussion, research and presentations, project-based learning, simulation and modelling. p. 6 Statistics is allocated five periods of 40 min each per week.
Technologies	Effectively use ICT tools to solve statistical problems. p. 5 Use ICT tools in statistical analysis. p. 6
Infrastructure	None was specified.

meant for those learners gifted in mathematics, communication skills are not emphasised.

Teaching-Learning Methods

The teaching and learning methods encouraged in the four Zimbabwean mathematics syllabuses are learner-centred and active learning. Learners need an education that offers opportunities to communicate, collaborate, solve problems, and think creatively and inventively. These skills and competencies are usually realised through blended learning - which combines face-to-face and e-learning. Blended learning entails optimising technology to obtain the competence and skills required to face the 4IR. All the four Zimbabwean mathematics syllabuses at the secondary school level are mainly anchored on the face-to-face mode of delivery and encourage learner-centred approaches to the teaching and learning of mathematics. Three of the syllabuses, except the statistics syllabus, list interactive e-learning as one of the teaching methods. However, the other three syllabuses do not indicate how interactive e-learning should be implemented in the Zimbabwean context.

Forty minutes are allocated for a mathematics lesson in the four syllabuses implying teachers have inadequate time to implement learner-centred approaches such as problem-solving and project-based learning, which are key to the 4IR. The success of using ICT tools hinges on the design of the ICT platforms and tools and the allocated time required to complete the detailed content in the curriculum (Sahal & Ozdemir, 2020). The component of formative assessment in the four syllabuses might imply spending more time on such assessments leaving inadequate time for learners' opportunities for creativity, innovativeness, problem solving and critical thinking.

Mathematics teaching and learning in Zimbabwe is confined to the four walls of the classroom where the teacher is in charge. This alone does not allow learners' creativity and innovativeness as required in the era of the 4IR.

Technology

The four syllabuses encourage the use of ICT tools in the teaching and learning of mathematics. However, it is not specified where and how the ICT tools should be used. Zimbabwean learners must memorise the geometry theorems and proofs for regurgitation during examinations despite the vast geometrical software freely available. This is because ICT tools are not emphasised as part of the teaching and assessment methods in the four syllabuses. The statistics and mathematics syllabus do not point out the use of Graphical software, Computer Algebra Systems and even the freely available Microsoft excel for teaching and learning statistics.

Regardless of technology innovations and advancements such as robots in science, technology, engineering and mathematics, the education sector has been unwilling to accept technology to facilitate teaching and learning (Oke & Fernande, 2020). The use of technology has been primarily limited to a didactic method of teaching and learning where teaching and learning are facilitated using a computer. Nonetheless, the technological approaches supporting the 4IR go beyond using a computer and electronic teaching resources and should be attuned to learner-centred approaches to be in a position to improve learners' learning experiences (Oke & Fernande, 2020).

Infrastructure

The Infrastructure that supports ICTs is one of the fundamental components of the education 4IR era. The Infrastructure required for teaching and learning mathematics is not indicated in Zimbabwe's mathematics four syllabuses. Infrastructure is one of the challenges that learning institutions must address, particularly in developing countries such as Zimbabwe.

Transforming the Zimbabwean Secondary School Mathematics Curriculum to Align with the Fourth Industrial Revolution Requirements

Our analysis of the Zimbabwean secondary school mathematics curriculum revealed that it does not provide learners with the necessary knowledge and competencies to perform in the 4IR. The rapid emergence of the 4IR digital technologies such as the IoT, CT, 3D printing, robotics, AR, VR, 5G networks, and AI has raised the urgency to adopt them in Zimbabwean mathematics education. However, there is no clear direction on how they should be integrated or how they should be implemented in the Zimbabwean mathematics curriculum. The curriculum needs to be transformed rather than reformed for the Zimbabwean mathematics curriculum to meet the requirements of the 4IR. Curriculum transformation focuses on generating new structures, yet reform focuses on existing systems (Akala, 2021). Zimbabwean mathematics curriculum transformation will help learners develop the skills and knowledge they need in the 4IR and establish thriving careers that are not endangered by the new technologies (Gwata, 2019). In the next sections, we propose how the Zimbabwean secondary school mathematics curriculum can be transformed to align with the 4IR requirements.

Collaboration Activities

Collaboration is a critical competence required for the 4IR. Employers in the 4IR era are looking for employees with collaboration skills. Collaboration skills are important in any workplace because teamwork drives productivity and promotes motivation and healthy employee relationships. As a result, collaboration skills need to be integrated into the Zimbabwean secondary school mathematics curriculum. Collaboration in the mathematics classroom requires learners to work together in pairs or groups to solve mathematical problems, develop mathematical ideas or complete projects. The Zimbabwean secondary school mathematics curriculum should provide exemplar activities that allow learners to work together and help each other. Zimbabwean mathematics teachers can adapt the exemplar activities according to their context or create similar activities that foster collaborative learning in their classrooms. The curriculum should require learners to work collaboratively on daily mathematics problems, activities, and projects. Teachers should check that each time learners work on tasks collaboratively, they agree or decide on the steps, strategies, processes and solutions as a group.

Collaborative learning help learners to organise and connect their mathematical thinking through communication, communicate their logical and clear mathematical thinking to their group members and teachers, and analyse and assess mathematical thinking and solution strategies other learners use (NCTM, 2000). As a result, working collaboratively in the mathematics classroom will help Zimbabwean learners develop interpersonal skills, communication skills, and knowledge-sharing techniques, which are necessary competencies to succeed in the 4IR. Learners who acquire these competencies from the classroom can easily apply them in their workplaces. Learners with collaboration skills are guaranteed to function seamlessly within workplaces of the 4IR.

New Literacies

Mathematics teaching and learning in Zimbabwe should focus on integrating digital literacy so that learners know how to use the recently developed technologies in the 4IR. Digital literacy is "the ability to find, evaluate, utilise, share, and create content using information technologies and the Internet" (Cornell University, n.d.). The Zimbabwean secondary school mathematics curriculum needs to add new literacies that require learners to read, collect, manage, evaluate, manipulate and use Big Data in their mathematics learning. The new literacies should also require learners to apply coding and AI technology in everyday mathematics. Zimbabwean mathematics learners must have a basic understanding of coding and AI concepts to interact efficaciously with AI systems in their future workplaces.

Mathematics Learning Factories

The Zimbabwean secondary school mathematics curriculum needs to integrate mathematics learning factories. Mathematics learning factories are collaborative spaces where practitioners benefit from the latest theory, research, and technology advances that mathematics learners bring. At the same time, mathematics learners learn from the practitioners and realise the practical advantages and disadvantages of implementing these theories, concepts and technologies in actual industrial settings. ICTs and VR technologies can create mock industries, allowing learners to visit industrial settings without interrupting processes or experiencing safety problems (Block et al., 2018). Mathematics learning factories help combine mathematics and real-life industrial settings to provide learners with a challenging and rewarding environment. Abele et al. (2015) observe that learning factories are an innovative way to simulate the industry settings for experimental and educational applications. In turn, this provides practitioners and learners with the opportunity to experience the industrial settings with the goal of understanding and integrating mathematical knowledge into contextual circumstances – a skill required in the 4IR.

Problem-Based Learning

Problem-based learning (PBL) should be integrated into the Zimbabwean secondary school mathematics curriculum. It is a teaching and learning approach that enables learners to learn mathematics while engaging actively with meaningful, ill-structured problems. This approach empowers learners to develop the necessary skills to solve real-world problems. PBL begins with an unstructured problem that the learners must solve using existing knowledge and new information they need to learn. If mathematics learners are confronted daily with ill-structured problems, they learn to apply new information to real-life problems, structure mathematical knowledge for future use in the 4IR, develop cognitive skills, and become lifelong learners. Moon and Seol (2017) observe that in the 4IR era, the idea of lifelong learning is high on the agenda. Dealing with ill-structured mathematical problems also helps learners to participate in learning actively and constructing knowledge rather than passively receiving information. As a result, learners acquire the necessary knowledge and competencies to solve future problems they will face at their workplaces in the 4IR era.

Our analysis revealed that the Zimbabwean secondary school mathematics curriculum predominantly focuses on structured problems. As a result, mathematical teaching and learning in the Zimbabwean classrooms are frequently guided by the assumption that each problem has one correct answer acceptable to the teacher. Consequently, learners' creativity is limited to replicating already known solution strategies and solutions (Renert, 2011). We recommend that the curriculum be revamped to make room for more ill-structured mathematical problems that require problem-based learning.

Infrastructure Relevant to Mathematics Teaching and Learning in the Fourth Industrial Revolution

We believe that technology on its own does not transform the mathematics curriculum; nonetheless, we recommend that the Zimbabwean government aim for interactive mathematics classrooms equipped with tablets that learners and teachers can use. The Egyptian government has done this where over 2000 schools have high-speed internet access, and 1.5 million tablets have been distributed to schools. The Egyptian government has also launched solar-powered smart classrooms, which are being built in rural areas, and the Zimbabwe government can follow the same route. Rwanda has endeavoured to electrify schools, allocate computers to all university students, and implement one laptop per child in schools (Munyengabe et al., 2017). This can also be done in Zimbabwe, a developing nation like Rwanda.

We recommend that the Zimbabwean government acquire technological gadgets like 3D Printing Pens to be used for teaching and learning mathematics in the Zimbabwean classrooms. The 3D Printing Pens can produce small, flat strings of molten thermoplastic on a surface or in the air. As the material hardens, it forms a volume of ink which simultaneously shapes into a 3D model. In contrast to a dormant 2D diagram drawn on paper with a pen or pencil, the 3D model can be manipulated. In this way, the Zimbabwean teachers and learners can interrelate with mathematics in a manner that is impossible when using computers, papers, pens or pencils. 3D models are essential for meaning-making in mathematics because they can be physically touched, transformed, or manipulated, thereby facilitating learners to learn abstract mathematical concepts physically through a trivial channel (Papert, 1980).

Conclusion

In the past couple of years, we have witnessed the emergence of various technological innovations from the 4IR, which have transformed the rules of the game regarding teaching and learning mathematics. Our analysis of the four Zimbabwean mathematics syllabuses revealed that learners are not being equipped with knowledge and skills that embrace 4IR technologies. Without the necessary knowledge and skills to compete in the 4IR era, Zimbabwean learners will not be prepared for the new jobs created. The Zimbabwean government needs to prepare learners with the knowledge and competencies that permit them to become productive employees and employers in the 4IR era. In this chapter, we have suggested how the Zimbabwean mathematics curriculum should be transformed so that learners can develop mathematics knowledge and competencies applicable in the 4IR era. Teachers' ability to teach in the 4IR was not the focus of this chapter; nonetheless, we recommend that the key stakeholders in Zimbabwe focus on developing the competencies, confidence, and desire of teachers to integrate technology into the teaching and learning of mathematics.

We are aware that mathematics education in 4IR requires investment, which can be challenging for a developing nation like Zimbabwe, still facing poverty. Nonetheless, like in Egypt, solar-powered classrooms can be constructed which make use of natural resources. We urge the Zimbabwean government to collaborate with non-governmental organisations and private companies to prioritise mathematics teacher and learner development in the 4IR. Zimbabwean private and public companies are already facing a dearth of 4IR skills, implying they need to invest in mathematics learners while still in school.

Future research should include teaching and learning systems that use AI, 3D printing, AR, robotics, IoT, and other technologies to learn more about the 4IR technology and how it affects the teaching and learning of mathematics in Zimbabwe. To better understand the various aspects of the 4IR technology and its impact on mathematics teaching and learning in Zimbabwe, future research should involve case studies, mixed methods research, and large sample surveys.

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